International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 5, May - 2014

Steady State Structural Analysis of High pressure Gas Turbine Blade

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***Abstract* - In present scenario, turbines play a crucial role in the field of power generation. Turbine blade is one of the major components of a turbine. But it accounts for maximum failures occurring in the gas turbines. So there is a pressing need for the analysis of various factors affecting the blade performance. The steady state structural analysis of a model of blade is carried out in this work using ANSYS software for different materials.**

The effect of centrifugal force and gas pressure on the High Pressure Turbine blade is thus computed. On analysis it is observed that the root of the blade is subjected to the maximum stress. Also, the blade section near the root has higher stress values as compared to the tip of the blade. Values of Von Misses stress and deformation are obtained for different blade materials and it is seen that at a turbine speed of about 3426 rpm Titanium Alloy exhibits the least amount of stress and undergoes very less deformation.

1. INTRODUCTION

A gas turbine is a form of turbine which uses highly pressurised gas as the working medium and is a component of a power plant which works on the principle of Brayton cycle.

The power plant mainly consists of an upstream rotating compressorwhich compresses the incoming ambient air to high pressure .This compressed air is then sent to the combustion chamber where it is mixed with fuel and heated to a high temperature. As a result, combustion takes place and hot gases with high energy content are generated. These hot gases are then transferred to the turbine where expansion takes place and the heat energy gets converted to rotary motion of the turbine shaft or mechanical energy. This turbine is usually coupled with a generator which then converts this mechanical energy to electrical output.

The blades of a turbine play a vital role in determining the life and overall efficiency of a gas turbine. Upon impingement by high pressure gases these blades rotate and produce mechanical work. A turbine usually consists of a series of stages .Each of these stages in turn consists of a series of blades attached in the form of a ring. They are mainly classified into: Stator blades and Rotor blades. While the stator blades are responsible for directing the gas flow and are designed in a way so as to compress the gas as it moves from one ring of rotor blade to another, the rotor blades are responsible for conversion of the gas energy to mechanical energy. The rotor blades are predominantly affected by the gaseous flow as they carry the entire flow load. Thus, it is of utmost importance to properly design the rotor blades.

The blades used in gas turbines have airfoil cross section to provide smooth directional flow of gases. In order to obtain maximum efficiency it is necessary that airflow across the airfoil is maximum. The blades are provided with shrouds to prevent leakage of flow thus effectively reducing the turbine losses. The roots of the blade generally have fir tree design which provides it with larger bearing area to take up the heavy stresses, and this bearing area is nearer to the axis of the blade resulting in resistance to cracking at the root as compared to the root in which the bearing area is at a more distance from the axis of the blade.

The turbine blade is subjected to various forces, primarily centrifugal and bending loads. The rotation of turbine results in Centrifugal forces and the Bending forces are the results of the fluid pressure and change of momentum.

From amongst these the centrifugal stresses having higher magnitude as compared to bending stresses are more significant. Centrifugal stresses depend on the mass of the material in the blade, blade length, cross-sectional area of blade and rotational speeds. The bending force exerted by the working fluid on the moving blade is in essence a distributed load, which varies along the blade height. Bending force can be resolved into two components viz. tangential and axial forces, where former is mainly responsible for power generation whereas the latter affects the flow of fluid over the blade.

2. LITERATURE SURVEY

Zuniga et.al[1] explains the design of a turbine in detail and follows the process given in “Design of High Efficiency Turbo machinery and Gas Turbines” by David Wilson. Velocity diagram, which is an important tool to describe velocity of fluid inlet flow velocity inside the turbine blades, is explained. The trajectory of air flow along the blades and various angles of fluid flow with respect to blade are schematically shown thus aiding in development of the blade profile of rotor and stator of turbine through various blade parameters.

Patsa and Mohammed [2] specify how to make effective use of the ANSYS pre-processor in analysing the complex turbine blade geometries. By applying boundary conditions to various blade materials like Monel-400, Haste alloy -x & Inconel 625, steady state thermal & structural performance is carried out. Finally, the results of the report are compared to the ones obtained in our analysis.

The works of Homji and Gabriles[3] provides an insight to the various modes of failures of gas turbine blades. The prominent of these are fatigue, creep, erosion wear, and environmental attacks and combined failure mechanisms.

Boyanapalli et.al[4] provides the dimensions of a gas turbine steam blades for its designing purpose. The dimensions in the stated paper are taken from the "NTPC" Ramagundam (2600 MW). Dimensions for the top, middle and bottom sections of the blade are given. In addition, the specifications for the bade for instance, normal rating, peak loading, rated speed, maximum/minimum speed, moment of inertia, et cetera are also mentioned, which have been used for calculation purposes of the stresses and forces.

Rao et al [5] presents the summary of blade data which has been helpful for the analysis. Details involving normal operating speed of machine, density, Poisson's ratio, ultimate tensile stress and so forth for blade material, $X_{20}Cr_{13}$ / $X_{20}CrMo_{13}$ are given.

In addition the steady state pressures for pressure surfaces and suction surfaces are also tabulated.

3. BLADE MODELLING AND ANALYSIS

The blade model profile is generated by using PRO-E software. The 3D profile of the blade is made by importing CMM coordinates into the software.. This model of turbine blade is then imported into ANSYS software. Meshing of the model is performed using Quadratic Hex mesh. For structural analysis structural boundary conditions namely displacement and force were applied on the rotor blade model. It was then analysed by providing suitable material and applying the centrifugal ,axial and tangential forces.

Details of Turbine Blade:

Diameter of blade mid span D = 1.3085m

Design speed of turbine N = 3426 rpm

Blade angle at inlet= 135.0170

Length of blade = 79.8 mm

Materials considered for analysis

I –N155 Alloy

II-Haste Alloy (Ni22Cr1.5Co1.9Fe0.7W9Mo0.07C0.005)

III-Inconel 165

IV-Molybdenum Alloy (Mo-52.5%, Rhenium-47.5)

V-Titanium alloy (Al-8%, Mo-1%,Ti-90%, VD-1%)

VI-Zirconium Alloy

VII-Super Alloy

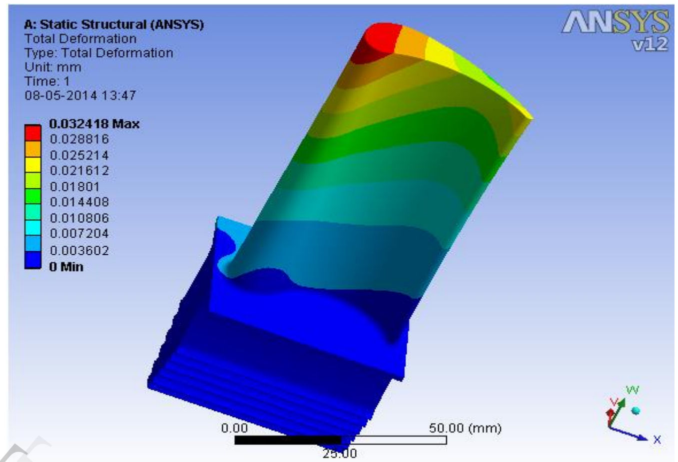

Fig 1. Deformation In Molybdenum

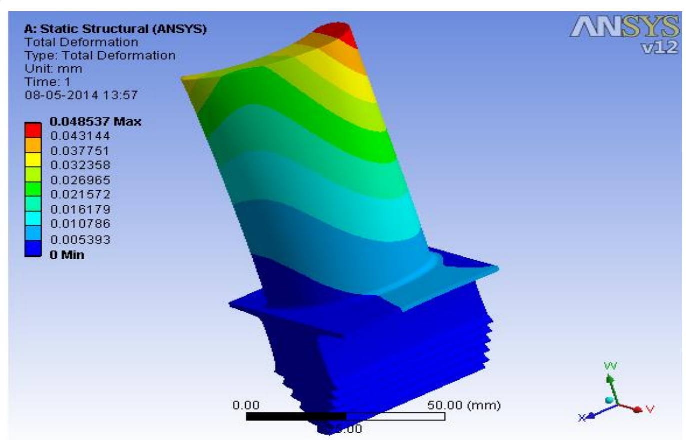

Fig 2. Deformation in Super alloy

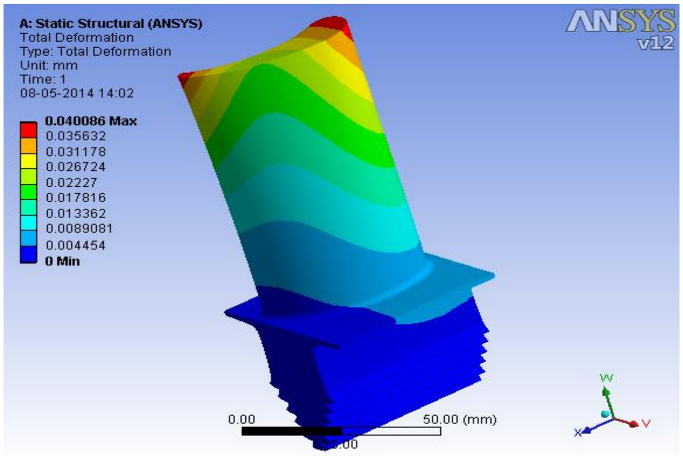

Fig 3. Deformation in Titanium

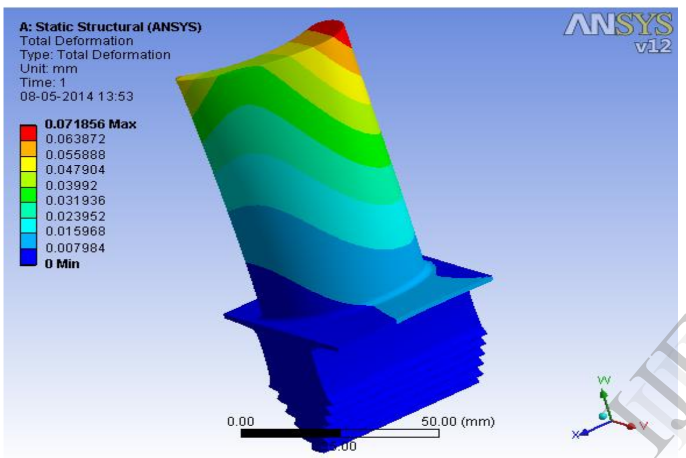

Fig 4. Deformation in N155

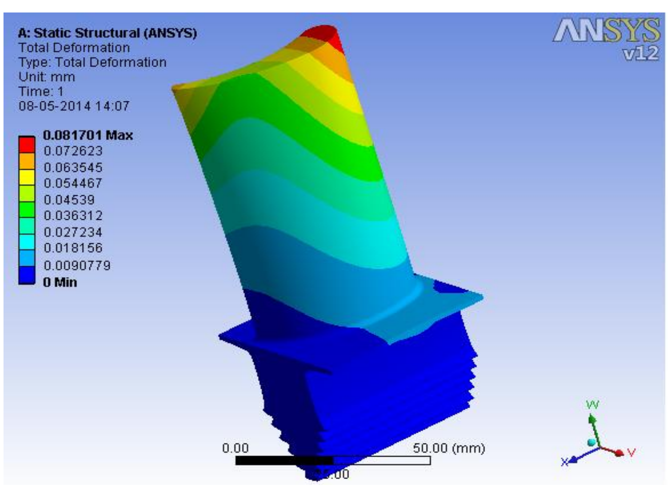

Fig 5. Deformation in Zirconium alloy

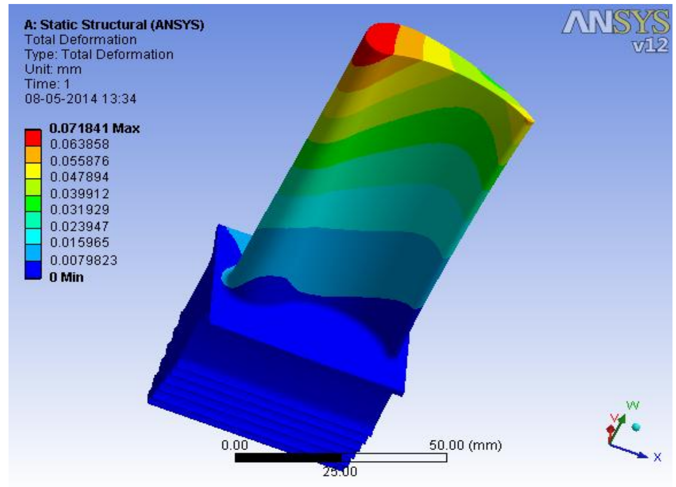

Fig 6. Deformation in Haste alloy

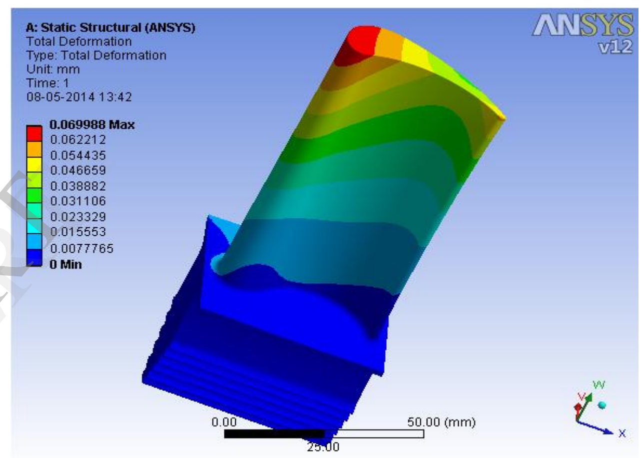

Fig 7. Deformation in Inconel 165

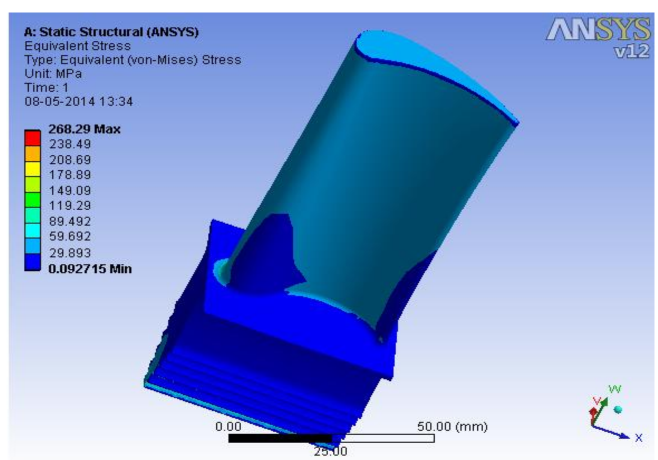

Fig 8. Von Misses stress in Haste alloy

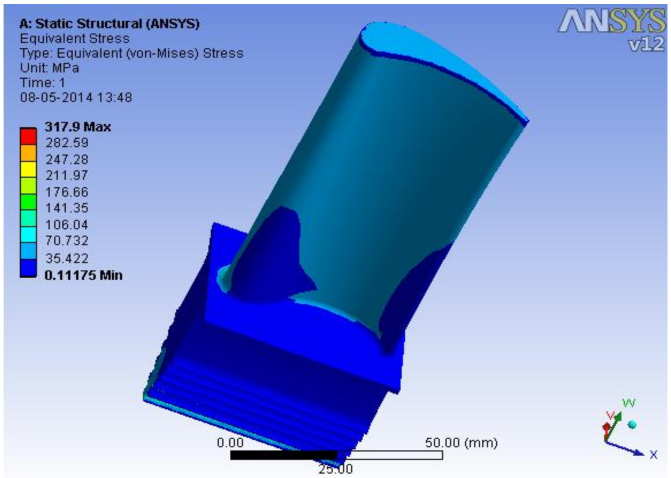

Fig 9. Von Misses stress in Molybdenum alloy

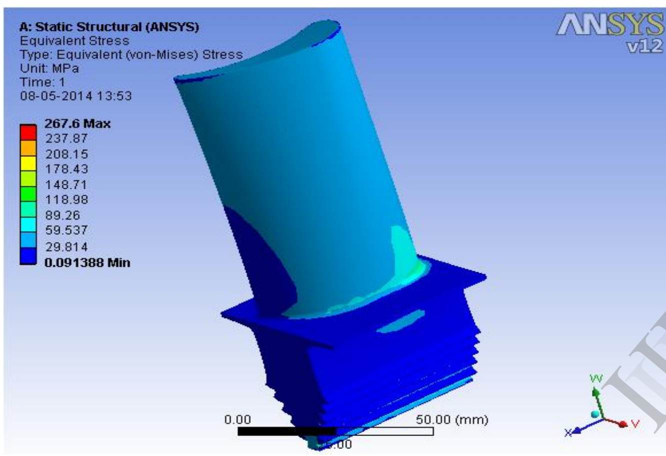

Fig 10. Von Misses stress in N155

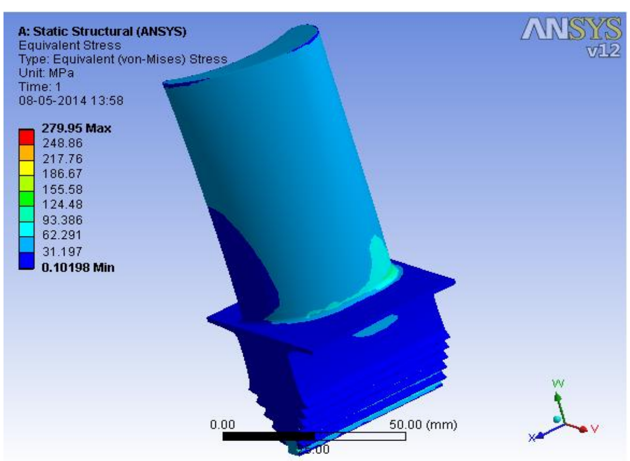

Fig 11. Von Misses stress in Super alloy

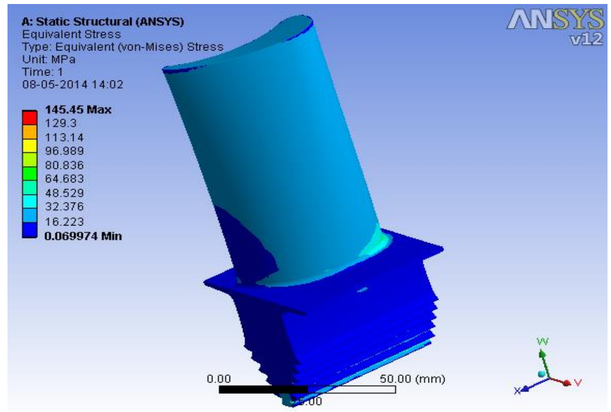

Fig 12. Von Misses stress in Titanium alloy

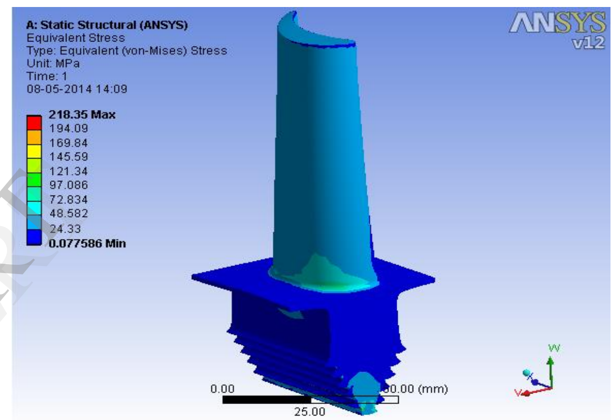

Fig 13. Von Misses stress in Zirconium alloy

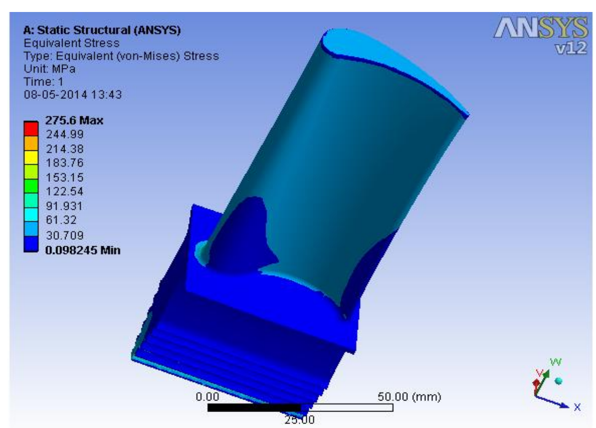

Fig 14. Von Misses stress in Inconel 165

4. RESULTS AND DISCUSSION

From the static structural analysis on a standing blade for various materials, the maximum stress and deformation is tabulated below:

MATERIAL	VON-MISSES STRESS (MPa)	DEFORMATION (mm)
Haste alloy	268.29	0.071841
Inconel 165	275.6	0.069988
Molybdenum alloy	317.9	0.032418
N155	267.6	0.071856
Super alloy	279.95	0.048537
Titanium alloy	145.45	0.040086
Zirconium alloy	218.35	0.081701

Table 1. Results of analysis

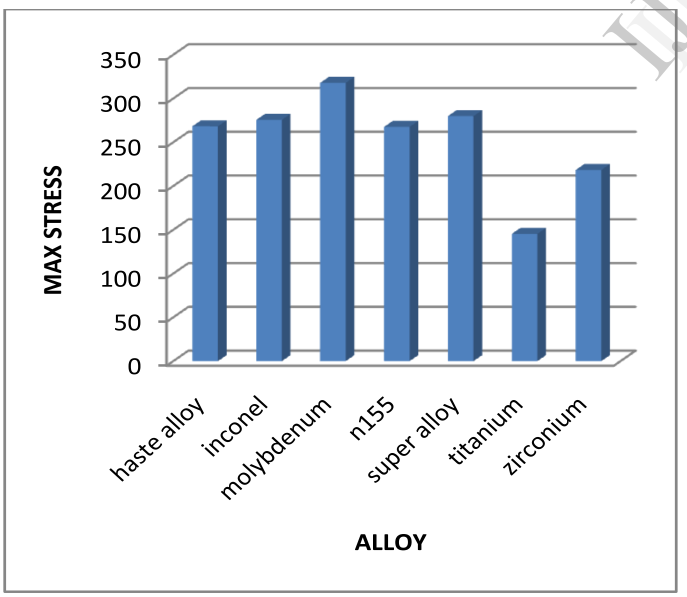

Fig 15. Comparison of Von Misses stress

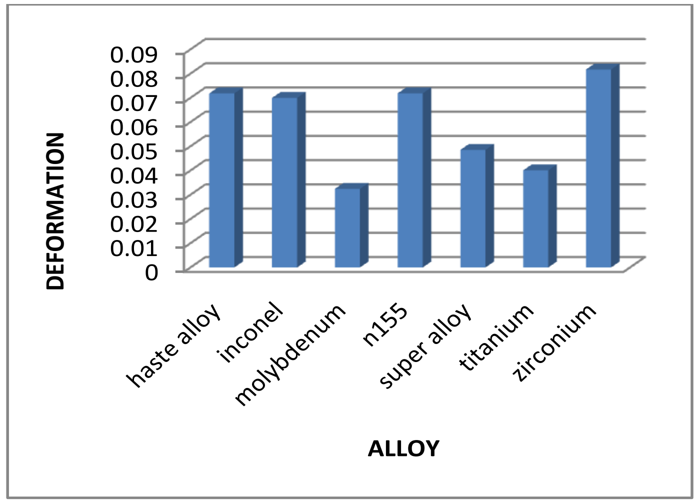

Fig 16. Comparison of Deformation

From the above chart, stress distribution of various materials is studied.

It can be seen that Titanium Alloy is subjected to minimum stress of 145.45 MPa.

Also it undergoes very less deformation i.e. of 0.040086 mm when the turbine rotates at 3426 rpm.

Zirconium alloy follows titanium alloy having a stress value of 218.35 MPa.

N155, Haste Alloy, Inconel and super alloy exhibit similar stress conditions, arranged in increasing order of stress values.

Among the studied materials, Molybdenum alloy has the highest stress value of 317.9 MPa, but has the least deformation of 0.032418 mm.

5. CONCLUSION

The Centrifugal, Axial and Tangential forces acting on the blade are considered as loads in **structural analysis**. From the structural analysis, it can be observed that the root of the blade is subjected to the maximum stress. Also, the blade section near the root at leading edge has higher stress values as compared to the tip of the blade. Maximum deflection was observed at the tip section of the blade, decreasing from leading edge to trailing edge and the root has minimum deformation as shown in Fig17. Comparative study reveals that the titanium alloy can be best suited for the turbine blade, considering only the effects of structural stresses.

These results can be utilised by the service technicians to have a closer look at the root and the leading section of the turbine, to ensure that cracks are not missed. This could be used to increase the efficiency of inspection processes.

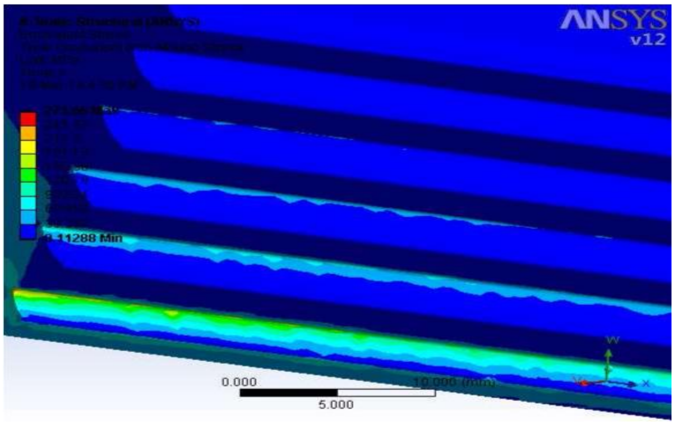

Fig 17. Stress variation in Blade Root

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